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Relation between Theoretical and Observational Models of the Upper Atmosphere

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In a recent paper [*Harris and Priester*, 1962] we published theoretical working models for the solar-cycle variation of the upper atmosphere that were based on a working hypothesis concerned with the dependence of the heat sources on the solar activity. In that paper we assumed that the fluxes of both heat sources (extreme ultraviolet flux and 'corpuscular' heat flux) vary in proportion to the monthly averages of the solar 10.7-cm flux, which is generally used as an indicator of solar activity. Consequently the model parameters S of the theoretical models were taken to be equal to the monthly averages of the 10.7-cm flux.

In addition to the comparison made earlier with data for high solar activity, it is now possible to compare those models with observational data obtained during times of medium and low solar activity. This leads to an improvement of the working hypothesis. The observational results used are the models by *King-Hele* [1963] for the years 1958–1959, 1960, 1961, and 1962. An appreciably good agreement is found for all levels of solar activity if we take into account how large the density changes are during the solar cycle. Toward the lowest level of solar activity, however, a systematic deviation appears that yields an empirical relation between the monthly averages of the solar 10.7-cm flux $\bar{F}$ and the model parameters S which is shown in Figure 1. This relation now replaces the working hypothesis used previously, and any user of our theoretical models should take the appropriate model according to this relation. The data given by *King-Hele* [1963] are yearly averages not corrected for the semiannual and annual variation [*Paetzold*, 1963]. Our theoretical models, on the other hand, are generally applicable to average values for the months September through December, because the observational models by *Martin et al.* [1961], on which the theoretical models are based, apply to the average densities of the months given above. Therefore we can consider the curve in Figure 1 as a lower limit. In particular, the open circles for $\bar{F} = 150$ and 100 might be placed slightly too low. A more

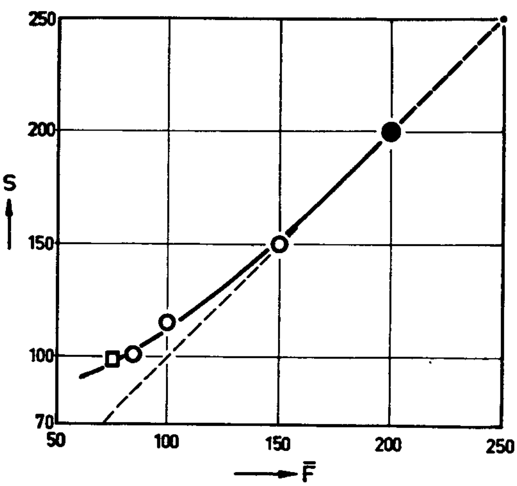

Fig. 1. Empirical relation between model numbers (Harris and Priester) S and the monthly averages of the solar 10.7-cm flux $\bar{F}$ as obtained from comparison with observational data: *open circles*, models by King-Hele for 1958–1959, 1960, 1961, 1962; *square*, first data by Explorer 17, launched April 2, 1963; *solid circle*, Bonn model for $\bar{F} = 200$. The dotted straight line represents the preliminary working hypothesis used in the paper by *Harris and Priester* [1962].

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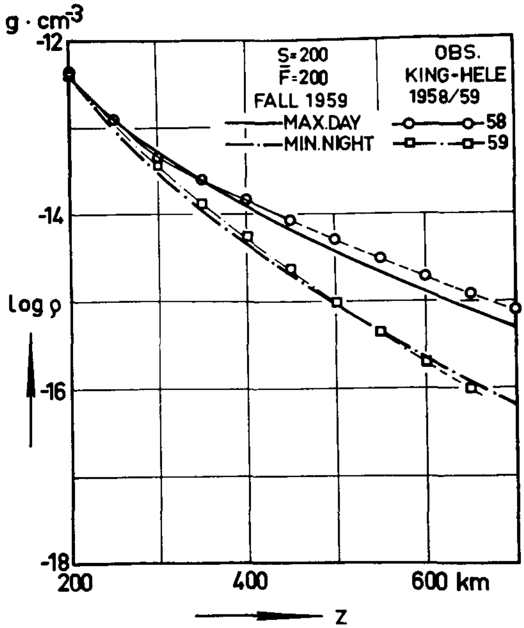

Fig. 2. Maximum daytime and minimum nighttime densities obtained by King-Hele from a large number of satellites are compared with the corresponding theoretical models by Harris and Priester. The observational curves are dashed at those altitudes where only a few data were available.

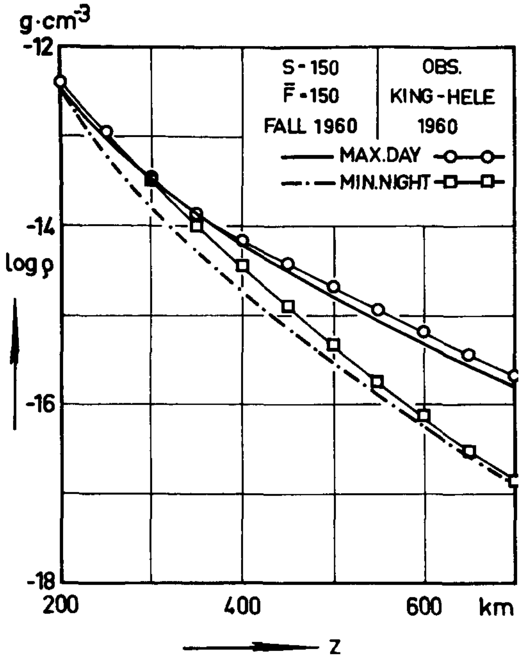

Fig. 3. Same as Figure 2.

refined analysis is presently being carried out by *Roemer* [1963*a*, *b*].

Figures 2 to 5 show a comparison between the observational and theoretical models using the new relationship. The observational daytime maximum curve in Figure 2 is for the year 1958 when the average of the solar 10.7-cm flux was 230. This accounts for the deviation from the theoretical model for an average flux of 200.

In Figure 3 the merging of the observational curves for daytime and nighttime at 300 km is believed to be influenced by the method of extrapolation to lower altitudes. Theoretical considerations [*Harris and Priester,* 1962] make a crossover between day and night curve very unlikely at an altitude as high as 300 km. Furthermore, *Jacchia and Slowey* [1962] found an appreciably larger diurnal amplitude at 350 km from Explorer 1 for the year 1960.

In Figure 4 it is seen that toward low solar activity the diurnal amplitude increases at low altitudes (300 km). The theory shows that this phenomenon follows from the lowering of the atomic oxygen layer during the decreasing phase of solar activity.

The pronounced increase (Figure 4) of the

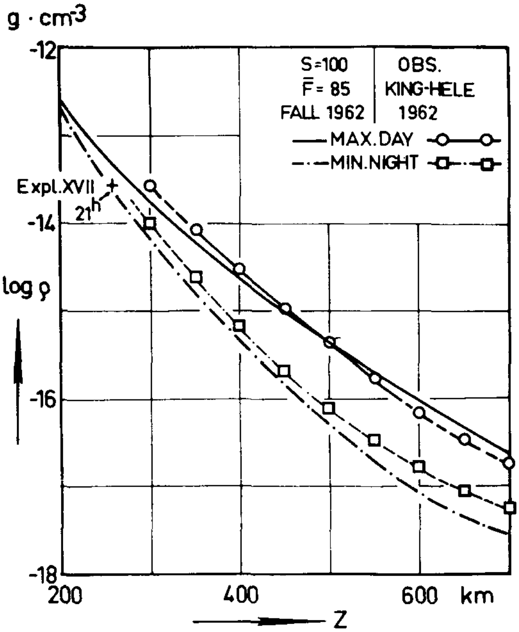

Fig. 4. Same as Figure 2. The density measured on April 3, 1963, at 2100 local time by Explorer 17 is also given.

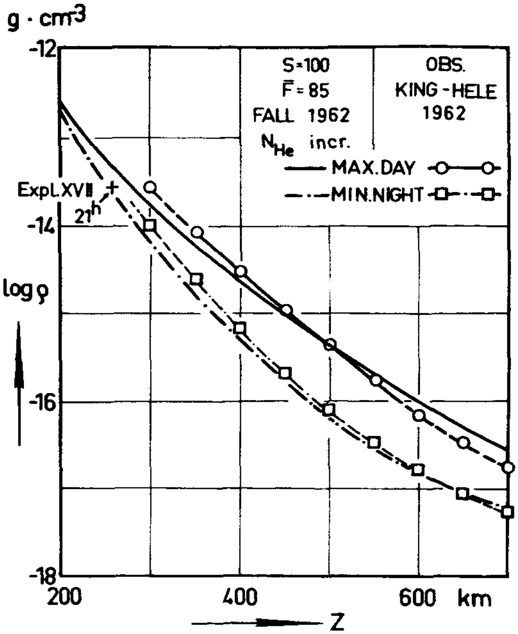

Fig. 5. Comparison between King-Hele's observed densities for 1962 and a new theoretical model containing an amount of helium increased by a factor 2.5 over that of the previous models. As in Figure 4, the density obtained by Explorer 17 is also given.

scale height at higher altitudes (above 600 km) can be explained by the lowering of the helium layer. The smaller diurnal amplitude in the observational curves above 600 km indicates that a greater amount of helium must be present than was assumed in the theoretical models. *Roemer* [1963*a*, *b*] finds better agreement with data obtained from Echo 1 when using a theoretical model which has a 2.5 times greater amount of helium (I. Harris, unpublished calculations, 1963) than the theoretical models mentioned above. In Figure 5 densities of this new model for $S = 100$ are compared with the appropriate data by King-Hele. The agreement between theory and observations is obviously even better than in Figure 4. In the models for higher levels of solar activities ($S \geq 150$), no noticeable increase of densities for heights up to 700 km occurs because of the increase of the number density N of helium by a factor of 2.5 at the boundary ($N(\mathrm{He}) = 6.25 \cdot 10^7$ cm^{-3} at an altitude of 120 km). For this reason, Figures 2 and 3 are also applicable for the new models.

Also shown in Figures 4 and 5 is a result obtained by Explorer 17 [*Horowitz et al.*, 1963] which fills a gap in our knowledge at low altitudes (below 300 km) for times of low solar activity. At 2100 local time, April 3, 1963, at 260-km altitude and temperate latitudes, the measured density was $2.7 \cdot 10^{-14}$ g cm^{-3}. The average solar 10.7-cm flux was about 75 in the usual units. Thus, if we use the relation shown in Figure 1, a theoretical model with parameter $S = 100$ is applicable.

If we plot the nighttime and daytime temperatures of the theoretical models using the new empirical relation (Figure 1), we obtain an excellent agreement with the nighttime temperatures derived by *Jacchia* [1963] who used *Nicolet's* [1961] models for the conversion of observed densities into temperatures (Figure 6). The daytime temperatures show a systematic difference of about 100° to 150°K. This could be explained by two reasons: (1) For a given density at any height Nicolet's models furnish one value for the temperature independently of local time, contrary to the Harris-Priester models, where the relation between density and temperature at a given height depends on local time (Figure 7). This is because the Harris-Priester models are solutions of the time-de-

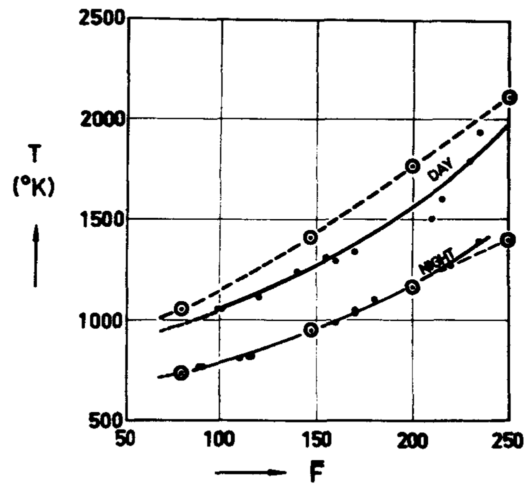

Fig. 6. Relation between exospheric temperature and the monthly averages of the solar 10.7-cm flux $\bar{F}$. The dots and small circles represent satellite drag data by *Jacchia* [1963] for nighttime and daytime, respectively. The temperatures are derived by means of Nicolet's model. The large circles give the temperatures of Harris-Priester models for 4 and 14 hours local time based on the empirical relation (Figure 1).

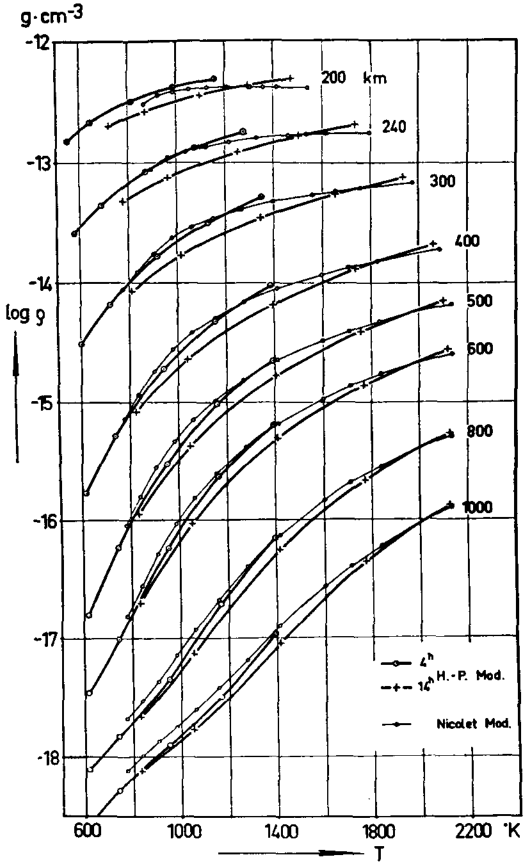

Fig. 7. Relation between density and temperature for eight different heights from 200 to 1000 km according to the Harris-Priester models for 0400 and 1400 local time (thick lines) and according to Nicolet's model (thin lines).

pendent heat conduction equation. Therefore the use of Nicolet's models for conversion of density into temperature would lead to a diurnal temperature amplitude that is too small. The difference depends on the altitude and the level of solar activity. For the data used by Jacchia, the difference can be estimated to be about 50° to 100°K. (2) The theoretical models of Harris and Priester are based on the observational model of Bonn Observatory [*Martin et al.*, 1961]. There are indications that the diurnal amplitude in this model is slightly too large, which again can account for a difference of 50° to 100°K.

Conclusions. The comparison with air densities observed within the period from 1958 to 1963 has shown that the theoretical models give a good representation of the atmospheric properties and their changes during the decreasing phase of solar activity if the relation given in Figure 1 is used. A still better agreement is obtained if in the theoretical models the amount of helium is increased by a factor of 2.5 at the boundary of 120 km. This, however, is important for periods of very low solar activity only. Further comparisons with forthcoming data for the years 1965 through 1968 will reveal whether the same empirical relation also holds for the increasing phase of the 11-year solar cycle.

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